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Mapping Ancient Baldcypress Forests for Conservation at Black River, North Carolina

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by

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Abstract

A few ancient baldcypress-bottomland hardwood forests survive across the southeastern United States in a mosaic of remnant old-growth stands left untouched by extensive logging during the early 20th century. Uncut stands in the Southeast that survived centuries of disturbance following European settlement tended to be too senescent and non-commercial to justify logging. Remnant ancient baldcypress forests at Black River, North Carolina, appear to contain the oldest living trees in eastern North America and The Nature Conservancy has protected several of these stands. However, the full extent of ancient bottomland forests along Black River is not known and many valuable tracts may be vulnerable to destruction in the increasingly developed floodplain. Locating additional old-growth parcels along Black River could help conserve the treasured biodiversity and water quality associated with North Carolina's bottomland forest habitat. This project used interpretation of high-resolution aerial imagery to locate potential areas of old-growth baldcypress forest along Black River, North Carolina. Identification of new, unprotected areas of ancient forest was based on image interpretation of previously identified old-growth stands, especially their site, situation, association, color and texture. The ages of candidate forest areas were verified in the field using expert visual assessment, photographic documentation and tree-ring analysis of increment cores taken from selected trees. Approximately 400 hectares (1,000 acres) of previously unidentified old-growth baldcypress-bottomland hardwood forests were mapped and are recommended as high-priority areas for future conservation efforts at both Black River and Island Creek, a blackwater tributary of the Northeast Cape Fear River. Centuries- to millennium-old trees were identified in all of these previously undocumented old-growth forests. These results indicate that ancient baldcypress forests extend almost continuously for 21 river miles along the mid- to lower-Black River and only 13 of these miles are protected by The Nature Conservancy.

Acknowledgements

This effort was made possible by the unending support of my advisor, mentor and friend Dr. David Stahle, whose confidence in me has quite literally elevated the trajectory of my life. If I can continue to make him proud in the decades to come, I will have succeeded. The loving kindness of my family – Joe, Mom, Dad, Devin, Katie, Felicity, Jeanne, Josh – gave me the motivation I needed during the past two years. Kemp Burdette, Angie Carl and Charles Robbins dedicated countless hours of their time and energy to help us complete our fieldwork on the Black River and their commitment to conserve North Carolina's natural areas has inspired me to follow suit. I feel privileged to have received counsel and assistance from Bruce Gorham, Bowei Xue, Dr. Xuan Shi, Dr. Jason Tullis and Dr. Ken Kvamme, without which I would have been quite lost. I am also honored and grateful that the Geosciences Department put their confidence in me as a teaching assistant; this experience prepared me for many future challenges. Above all, I have immeasurable gratitude for Joe Spike Green. Joe's spirited generosity inspires me every day and he could never be fully repaid for the compassion he showed me during this journey.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Rapacious logging during the early 20th century left very few ancient baldcypress (*Taxodium distichum*) forests in the southeastern United States. Only three sizable tracts of tall, columnar baldcypress have been preserved, including Four Holes Swamp in South Carolina (Audubon Society and The Nature Conservancy), Corkscrew Swamp Sanctuary in Florida (Audubon Society) and Grassy Lake, Arkansas (private hunting club). However, additional parcels of ancient baldcypress forest survive in a mosaic pattern across the southeastern United States at sites where trees were too small, poorly formed or senescent to justify logging. Thousands of hectares of noncommercial baldcypress forest may remain unidentified and unprotected on private land. Most of these remnant stands are small (< 50 hectares), but have survived centuries of disturbance following European settlement and represent an important component of eastern North America's dwindling biodiversity. Indeed, the importance of conserving the remaining old-growth forests of eastern North America for biodiversity has been well established (Davis 1996).

One outstanding example is located along Black River, North Carolina, where ancient baldcypress forests appear to contain the oldest living trees in the eastern United States. The oldest positively identified baldcypress at Black River was 1,622 years old when it was cored as a living tree in 1985 (BLK69; Stahle et al. 1988, 2012). This specimen is still living and has reached 1,652 years of age. Northern white cedar (*Thuja occidentalis*) also attains great age in eastern North America and one sample from a dead log has been documented with 1,653 annual rings (Pederson 2013). This means that BLK69 is the oldest living tree ever documented in eastern North America and in 2016 it will be the oldest tree living or dead to be documented in this region. In fact, hundreds of millennium-age trees are present at Black River and some may

be over 2,000 years old. Millennium-age baldcypress trees along Black River have been used to reconstruct past climate over North Carolina (Stahle et al. 1988) and over 3,000 acres of bottomland forest have been protected by The Nature Conservancy as The Black River Preserve (The Nature Conservancy; see Chapter 3, Figure 6). However, the full extent of ancient forests along the 66-mile-long Black River (The Nature Conservancy, http://www.nature.org/) is not known and hundreds of additional hectares may exist. These additional parcels of ancient forest are vulnerable to destruction and need to be identified as the first step toward their conservation management.

The vast majority of tall, columnar, mature baldcypress forests in the Southeast were harvested for timber during the early 20th century (Mattoon 1915). However, some stunted, inaccessible and noncommercial trees were often left standing (Stahle et al. 2012). Remnant stands of ancient baldcypress along Black River tend to exhibit these noncommercial structural qualities, including twisted stems, broken and disproportionately small canopies and hollow voids, which make them visually distinct from the surrounding managed forests and agricultural landscape in high-resolution aerial imagery. Expert photo interpretation and GIS-enabled image classification techniques can potentially exploit the distinct site and structural characteristics of old-growth baldcypress stands at Black River in order to identify additional tracts of ancient baldcypress that were previously unknown and unmapped. The mapping of old-growth forest parcels along Black River could contribute to the conservation of one of the most unique ecosystems in the eastern United States.

This project used high-resolution aerial image interpretation and ancillary GIS mapping layers to identify candidate areas of ancient baldcypress on Black River not currently under conservation management. Fieldwork was conducted in March 2015 to verify the locations of

ancient forest tracts using expert assessment of old-growth characteristics, photographs and tree-ring analysis of increment cores taken from selected old trees. Although this verification was not based on rigorously randomized field surveys, several new tracts of ancient baldcypress and bottomland-hardwood forest were identified on the Black River and on Island Creek, a blackwater tributary of the Northeast Cape Fear River.

Chapter 2: Background

The geographical range of baldcypress spans the southeastern United States, largely confined to the Atlantic and Gulf Coastal Plains and the lower Mississippi Valley, where it is the longest-lived native tree species (Figure 1). The closely related Montezuma baldcypress (*Taxodium mucronatum*) also attains great age and is the longest-lived species native to Mexico and Guatemala (Figure 1). Dendrochronology and dendroclimatology initially focused largely on arid-site conifers throughout the Great Basin region of the United States due to the remarkable longevity and the exceptional moisture sensitivity expressed in the annual growth rings of these species. Bristlecone pine (*Pinus longaeva*) is the longest-lived tree species in the world (Brown 2013). In the White Mountains of California, one living bristlecone pine has been dated at 5,062 years old and two more have been dated at over 4,800 years old (Brown 2013). Following the discovery of significant moisture sensitivity exhibited by annual rings of baldcypress despite frequent inundation, the University of Arkansas Tree-Ring Laboratory (UAF TRL) has worked for three decades to develop long baldcypress tree-ring chronologies at sites throughout its native range (Figure 2). The baldcypress tree-ring chronologies mapped in Figure 2 include the oldest-known trees in Mexico and in the southeastern United States (Stahle et al. 2012).

Within its natural range, baldcypress tends to occupy the lowest-lying portions of floodplains, where it colonizes backwater swamps and wet depressions (Mattoon 1915). Indeed, some 90 percent of baldcypress stands within their native range occupy sites below 30 meters in elevation (Wilhite and Toliver 1990). Flood-tolerant baldcypress and hardwoods cohabit the subtle ridges and depressions that flank major watercourses in this region to form bottomland hardwood swamps, an ecosystem that dominates much of the southeastern landscape (Wharton et al. 1982). Southeastern swamps are often categorized according to their geologic age, sediment

load, nutrient availability and degree of acidity. “Brownwater” swamps in the Southeast occupy relatively young floodplains, where the sediment load is dominated by inorganic components weathered from rock and soil (Mattoon 1915; Wharton et al. 1982). Blackwater rivers carry water that is typically clear and stained black or tea-colored by tannins and other organic matter.

Bottomland hardwood swamps are characterized by frequent and sometimes long-term inundation. Persistently saturated soils create anaerobic conditions that vary in depth across time and space according to local topography and hydro-period. This anaerobic gradient, shaped by flood frequency and duration, is the primary factor controlling plant distribution in floodplain forest communities, as plant species are selected according to their tolerance of stresses induced during saturated, anaerobic conditions (Wharton et al. 1982). Biological activity during periodic or permanently flooded conditions can deplete oxygen availability within the saturated soil column, causing plants to initiate anaerobic respiration processes that damage root function and trigger the build-up of toxic elements in plant tissue. Baldcypress has advantageously adapted to the lowest and wettest situations within swamp landscapes by developing special root structures that protect tissues and preserve respiratory functions during the physiological stress induced by anaerobic soil conditions (Wharton et al. 1982; Figure 3). Furthermore, floodwaters are an important component of baldcypress seed dispersal (Wilhite and Toliver 1990). Wetland hardwood and conifer species like overcup oak (*Quercus lyrata*), red maple (*Acer rubrum*), water tupelo (*Nyssa aquatic*) and loblolly pine (*Pinus taeda*) tend to colonize neighboring ridges built up by alluvial processes, where baldcypress cannot compete as efficiently for light and soil moisture (Mattoon 1915, Dennis 1988).

Baldcypress lumber is valuable for its moderate softness, large columnar form and extreme durability (Mattoon 1915, Wilhite and Toliver 1990). When exposed to soil, water or

air, baldcypress heartwood resists decay long enough that it often begins to weather mechanically before weathering chemically. Though commercially valuable tracts of baldcypress initially were preserved in swamps that were largely inaccessible to logging outfits, the introduction of advanced logging methods in the early 1900's allowed exploitation of even these remote forests. In particular, the installation of overhead cableway skidders for timber transport across deep swamps opened up a wealth of baldcypress that had been previously untouched due to soft ground and persistent flooding (Mattoon 1915). Consequently, an enormous fraction of southeastern baldcypress forests were logged during the early 20th century. Of the 17 million hectares of undisturbed swampland estimated by forest examiner Wilbur Mattoon to have originally covered the Southeast, only 5,000 hectares is estimated to remain, representing a more than 99 percent reduction in uncut baldcypress forests across the southeastern United States (Mattoon 1915; Stahle et al. 2006).

The specific germination and growth requirements of baldcypress demand a unique set of circumstances in the hydrogeology of the stream corridor in order for a large successful recruitment of seedlings to take place. Baldcypress seeds will not germinate in water and the seedlings and saplings cannot tolerate extended inundation (Wilhite and Toliver 1990). Soil moisture must be abundant enough to encourage seed germination, but flooding must remain minimal while seedlings and saplings are small in order to prevent drowning. The episodic tendency for successful baldcypress recruitment may be related to the beneficial growth conditions created by prolonged, decadal droughts in excessively wet swamps (Stahle et al. 2012), which are common to the southeastern moisture regime according to tree-ring reconstructions of past climate (Stahle et al. 1988). Episodic baldcypress recruitment contributes to its cohort-based sprouting, growth and senescence (Mattoon 1915). Mattoon referred to this

phenomenon as "even-age trees in all-age stands," and illustrated its effect on baldcypress age and timber quality, which appear to be controlled by subtle changes in soil, water pH, species composition and stream geomorphology across the swamp landscape. Figure 4 is a schematic illustration of the distribution of baldcypress trees of various ages, sizes and lumber values in lacustrine and alluvial swamps of the southeastern United States (from Mattoon 1915).

Twentieth century logging efforts decimated the majority of standing baldcypress across the Southeast. The fragmentary stands of baldcypress that survived logging in the 20th century tend to exhibit qualities not valuable for timber production (Stahle 1996; Stahle et al. 2012). Inaccessibility due to flooding or soft ground rendered certain stands too costly to profitably cut (Mattoon 1915; Stahle et al. 2006). Baldcypress in acidic, nutrient-poor back swamps with huge fluctuations in water level tend to grow very slowly, achieving great age while remaining too stunted or poorly formed for valuable lumber (Stahle 1996). Old baldcypress near the Atlantic and Gulf coasts have survived centuries of wind damage during hurricanes and other storms that pruned large branches until the crowns became "flat-topped" and disproportionately small when compared with their study bases (so-called "under-fit canopies"), leaving ancient trees with a twisted, branchy and irregular growth form not ideal for timber production (Stahle 1996). Streamside baldcypress along bayous or sloughs also often exhibit asymmetrical form and low branching as they grow sideways toward direct sunlight afforded by the open stream corridor. Very old baldcypress are often partially hollow from decay. Baldcypress stands exhibiting these noncommercial qualities were sometimes deemed "over mature" by the logging industry and either skipped over or selectively logged so that the small, defective, but often very ancient trees were left behind (Mattoon 1915; Stahle et al. 2006 and 2012).

The unique structural and site characteristics that made ancient baldcypress less valuable to the logging industry also make them visually distinct to trained naturalists. Experts have used the stunted and irregular structural characteristics of trees for decades to locate the oldest specimens in the field for the development of long tree-ring chronologies and climate reconstructions (Stahle 1996). Old-growth baldcypress stands along Black River, North Carolina, exhibit distinct color, texture, site, situation and association characteristics in high-resolution aerial imagery that can be used to discriminate them from surrounding land cover classes. The efficacy of human visual analysis of aerial imagery using nine basic elements of image interpretation (color, size, shape, texture, pattern, shadow, site, situation and association) is well established and this technique has been used in natural resource assessment for decades (Olson 1960, Jensen 2006). Quantitative forestry characteristics such as stand age, canopy height and stem area have been reliably estimated using manual high-resolution photo interpretation techniques (e.g., Holmström, Nilsson and Ståhl 2001). Combining expert field knowledge of remnant old-growth forest characteristics with high-resolution image interpretation could be an effective tool for identifying potential old-growth areas for research and conservation.

Texture is a particularly important characteristic for the evaluation of old-growth forests using photo interpretation (Olson 1960, Franklin et al. 2000). At stand and landscape levels, some ancient forests exhibit multiple distinct canopy layers and this relatively complex vertical structure tends to make primary forest parcels distinguishable from surrounding secondary growth in remotely sensed imagery (Franklin and Van Pelt 2004, Spies and Franklin 1991, Olson 1960). Uncut forest tracts are often characterized by irregular gaps in canopy coverage and dense patches of regrowth caused by centuries of natural stand-replacing disturbances (Franklin and Van Pelt 2004, Franklin et al. 2002). Correlation between the spatial complexity of a stand's

canopy and its age allows for the discrimination of forest age classes in high-resolution aerial imagery and more recently using LiDAR data (Olson 1960, Lefsky et al. 1999). The canopy structural complexity associated with mature forests is often visible in aerial imagery as a rough, cobbled texture when compared to the smoother, more "velvety" texture of younger canopies (Olson 1960). The recent rapid development of object-based image analysis has now allowed for quantification of these vegetation texture properties for automated classification of land cover categories using remotely sensed imagery (Haralick 1973, Blaschke 2010).

The vertical and horizontal complexity of mature forest stands in the Pacific Northwest contributes to their function as preferential habitat for threatened or extirpated species like the marbled murrelet (*Brachyramphus marmoratus*) and northern spotted own (*Strix occidentalis caurina*) (Hamer et al. 1995, Oregon Fish and Wildlife 2014). Likewise, a significant fraction of threatened species native to the Southeast depend on bottomland forests for habitat and it may not be coincidental that the ivory-billed woodpecker (*Campephilus principalis*) was reported in ancient baldcypress forests at Bayou DeView, Arkansas (Fitzpatrick et al. 2005), or that the swallow-tailed kite (*Elanoides forficatus*) and endangered wood stork (*Mycteria americana*) have both recently returned to ancient baldcypress stands at Black River, North Carolina (Angie Carl, The Nature Conservancy, personal communication, March 23, 2015).

Site, situation and association characteristics consider the arrangement and distribution of objects in an image and are especially useful for locating candidate areas of remnant old-growth baldcypress because they capitalize on an analyst's ability to synthesize several distinct properties of noncommercial baldcypress stands within an extensively developed landscape. Remnant ancient stands tend to be located on sites in the lowest-lying areas of a floodplain, where forests are frequently and deeply inundated and canopies are overwhelmingly dominated

by flood-tolerant baldcypress. These sites are often associated with sluggish back sloughs that are located away from main river channels and disappear gradually underneath increasingly closed canopies on slightly higher and less frequently flooded terrain. Remnant old-growth baldcypress stands in North Carolina are often insulated by surrounding stands of pine or hardwoods growing on slightly higher ground within forested floodplains, which were sometimes more accessible and more valuable for logging. Site, situation and association information in imagery is contextual and most useful when considered synergistically by experts with field knowledge of target objects (Jensen 2006). The ability to interpret images using these contextual characteristics has historically been underutilized by automated computer algorithms, but has recently been incorporated into object-based image analysis research (O'Neil-Dunne, MacFaden and Pelletier 2011).

Though the automated classification of remnant old-growth forests in the eastern U.S. has not been fully explored, some GIS analysis has been incorporated into projects seeking to locate ancient stands of Cross Timbers species in Oklahoma and Texas. These GIS-enabled habitat suitability models for old-growth forests have proved useful in human-altered landscapes, where remnant uncut stands can be discriminated from adjacent developed land cover and are distributed according to the predictable qualities that might have spared them from logging. An old-growth prediction model was successfully employed in the Cross Timbers of Oklahoma, where soil series and slope requirements were used to map areas of probable ancient forest in the satellite-derived extent of still-wooded landscape (Therrell and Stahle 1998). Subsequent field assessment using randomized field surveys and dendrochronology verified the model as having predicted the extent of old growth in the study area with 94 percent accuracy. Randomized field-testing of a similar model using Landsat imagery and a digital elevation model (DEM) was 77

percent accurate and identified 41, 958 hectares of potential old-growth Cross Timbers woodlands in eastern Oklahoma (Bayard 2003).

Another habitat suitability model employed automated Landsat image classification, land cover change analysis and slope in order to map probable old-growth Cross Timbers forest in north-central Texas (Peppers 2004). Though the overall prediction accuracy was lower, the model identified several large, previously unknown and unmapped tracts of ancient Cross Timbers forest. Landsat imagery was found to be insufficient for discriminating between old- and second-growth post oak forest using Maximum Likelihood Classification, but slope was found to be a significant predictor for old-growth post oak sites in Texas. Though automated classification techniques may be unnecessary for the location of unprotected parcels of ancient baldcypress forest on Black River, North Carolina, ancillary digital map products like Landsat, MODIS (Moderate Resolution Imaging Spectroradiometer) and DEM data could be combined with the interpretation of high-resolution imagery and used to identify characteristics common to baldcypress stands in order to systematically distinguish ancient forest parcels from the surrounding landscape across the Southeast.

This study will analyze high-resolution orthoimagery, digital elevation data and parcel ownership data in order to test the hypothesis that remnant stands of old-growth baldcypress survive outside of conservation property on Black River, North Carolina. If remnant stands can be identified, the methods used in this study could be applicable for ancient baldcypress forests elsewhere in the southeastern United States.

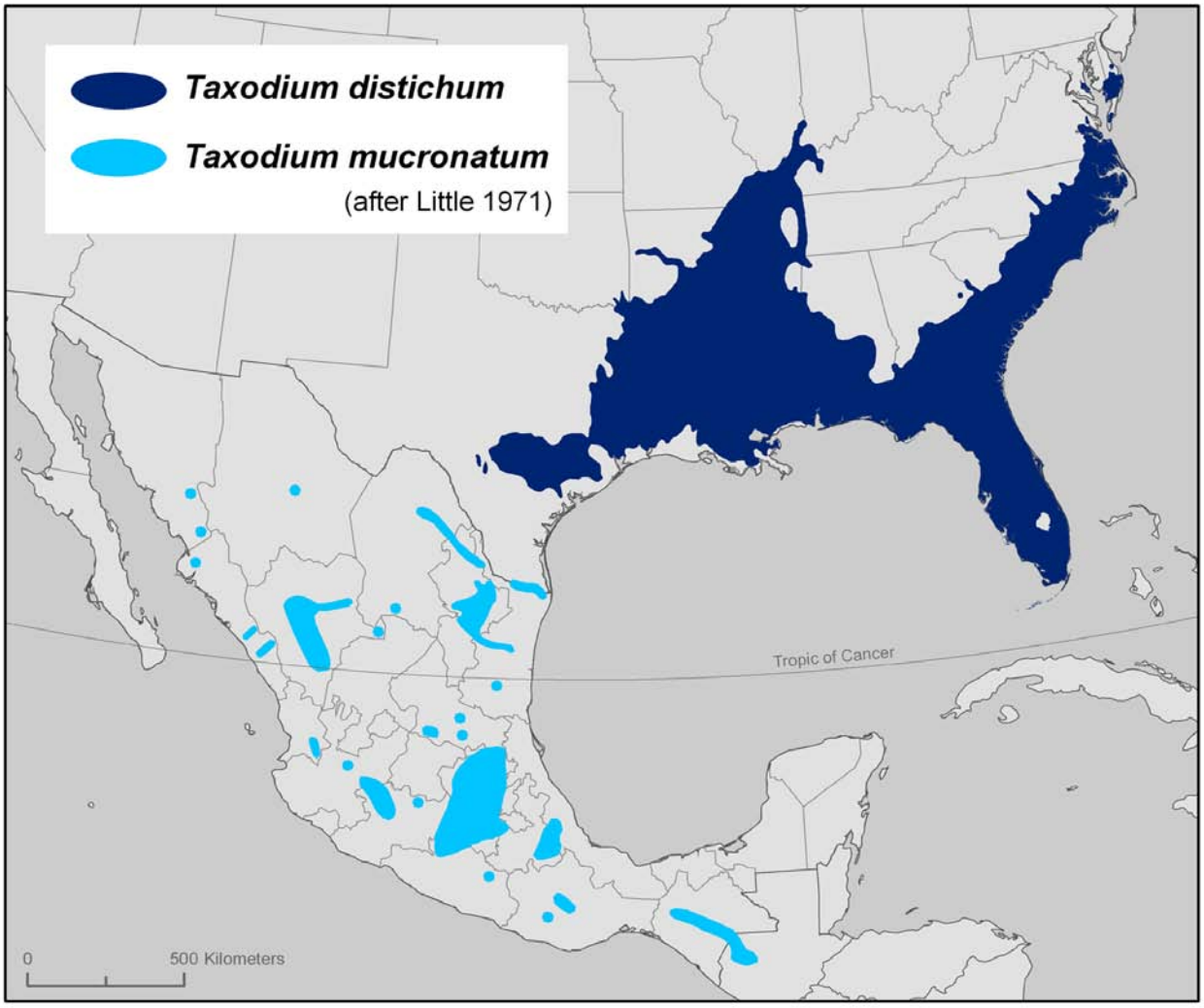

Figure 1: The distribution of baldcypress (*Taxodium distichum*) is largely confined to the Atlantic and Gulf coastal plains and extends up the Mississippi River Valley. A close relative, Montezuma baldcypress (*Taxodium mucronatum),* is found in isolated patches of riparian habitat throughout Mexico and portions of western Guatemala (Stahle et al. 2012, used with permission).

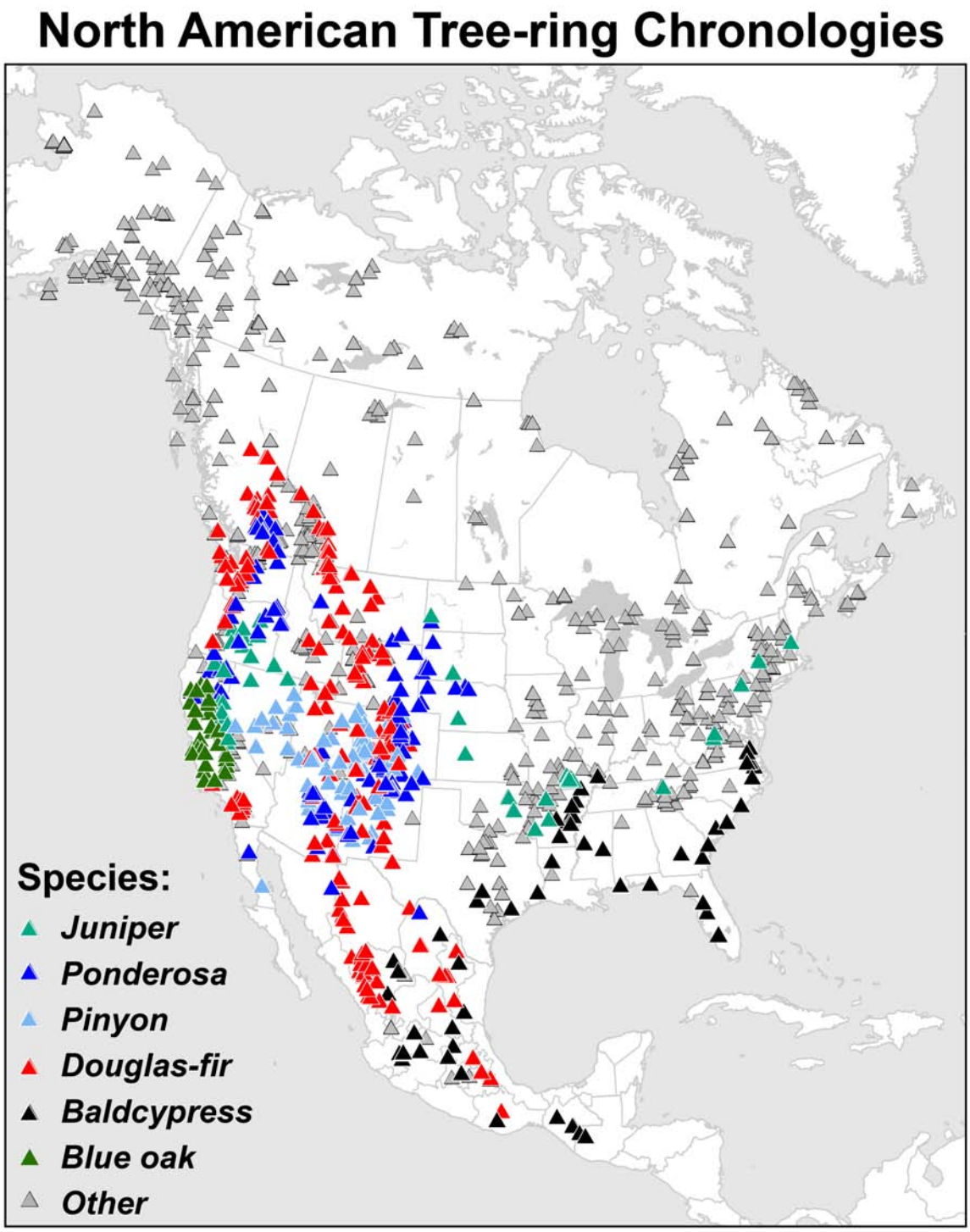

Figure 2: The locations of North American tree-ring chronologies are mapped and include Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), pinyon (*Pinus edulis* and *Pinus monophylla*) and blue oak in the West, and baldcypress throughout the southeastern United States and in Mexico. The University of Arkansas Tree-Ring Laboratory has developed the majority of the baldcypress tree-ring chronologies, in collaboration with Dr. Jose Villanueva in Mexico (used with permission from David Stahle).

Figure 3: Ancient baldcypress are illustrated in the Three Sisters area of Black River, North Carolina, during extreme low water conditions. The two trees at left have not been sampled for dendrochronology but are almost certainly over 1,000 years old and may even be 2,000 years old (David Stahle, personal communication, April 7, 2015). Note the black or tea-colored water and the baldcypress knees (photo used with permission from Dan Griffin).

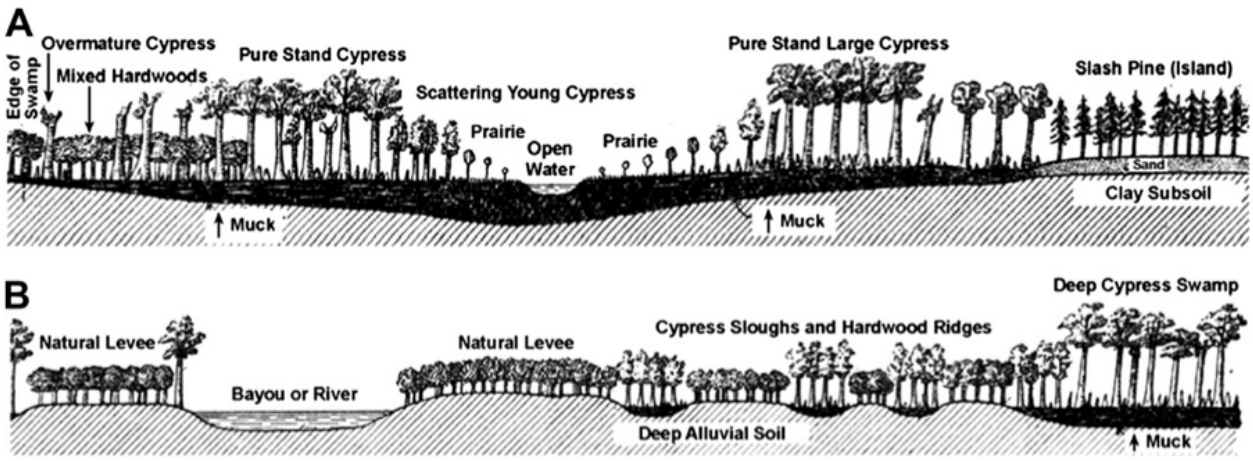

Figure 4: Mattoon's (1915) schematic profile illustrates the distribution of commercial and noncommercial cypress stands according to subtle landscape changes across an alluvial (A) and non-alluvial swamp (B). Areas with stands deemed "over mature" (A) by the logging industry could contain remnant old-growth baldcypress stands today (note their broken canopies and open stand structure). Likewise, the stunted asymmetrical canopies of streamside baldcypress found along "cypress sloughs" (B) were often unsuitable for lumber production.

Chapter 3: History of Conservation along Black River, North Carolina

Black River is one of the great natural areas in the United States. Thousands of acres of stunted and wind-sculpted baldcypress flank the pristine channel, whose waters have been designated as an Outstanding Water Resource for the state of North Carolina (The Nature Conservancy, "Black River Preserve," http://www.nature.org/). Despite the importance of the river as a commercial highway for steamboats and timber operations during the 18th and 19th centuries, some baldcypress and bottomland hardwood forests along Black River survived logging by virtue of being hollow, branchy, stunted or too difficult to harvest when compared with available tracts of upland pine (Mattoon 1915, Earley 1990, Stahle 1996). As a result, baldcypress stands along Black River contain what is most likely the highest concentration of millennium-age trees in eastern North America (Pederson 2013). Only a handful of tree species grow to be over 1,500 years old (Brown 2013), and for some species, such long-lived specimens are rare (David Stahle, personal communication, April 7, 2015). However, there appear to be hundreds of millennium-age baldcypress along Black River, along with significant numbers of old-growth tupelo, overcup oak and other bottomland species. In fact, the oldest known living trees in eastern North America are found at Black River, North Carolina.

Conservation interest at Black River appears to have begun when Steve Leonard recommended the river as a high-priority natural area in a site description delivered to the North Carolina Natural Heritage Program in 1981. Leonard described the numerous low, divergent sloughs along the river, where water depth gradually decreases into stands of baldcypress and the mixed bottomland hardwoods that grow on slightly higher sandbars and natural levees. His report identified the existence of four endangered species of vegetation along the river: water arrowhead (*Sagittaria latifolia*), sarvis-leaf holly (*Ilex amelanchier*), greenfly orchid

(*Epidendrum magnolia*) and May hawthorn (*Crataegus aestivalis*; Leonard and Davis 1981). Leonard argued that the most important feature in the area of Black River studied for the report was a sizeable tract of "extraordinarily large" baldcypress trees containing significant amounts of rare understory species. He named this tract the "Larkins Cove Cypress Forest" and recommended this "spectacular" area for protection and study by the North Carolina Natural Heritage Program.

At the Heritage Program's suggestion, the University of Arkansas Tree-Ring Laboratory explored Larkins Cove and surrounding forests along the Black River in 1985 and 1986 for a research project designed to develop tree-ring chronologies for long-term climate reconstruction for the southeastern United States. Long-lived baldcypress trees are valuable for dendroclimatic reconstruction because their annual growth is remarkably sensitive to variation in seasonal precipitation despite their frequent inundation (Stahle et al. 1988, Stahle et al. 2012). The climate sensitivity of baldcypress may be influenced by changes in the anaerobic gradient throughout the soil and water column caused by anomalous dry or wet conditions (Stahle and Cleaveland 1992). The Tree-Ring Laboratory's original fieldwork at Black River resulted in the collection of the oldest baldcypresses yet dated using dendrochronology and established a legacy of research analyzing past seasonal moisture regimes over the Southeast. Millennium-age baldcypress trees at Black River led to the development of a more than 1,600-year-long time series reconstruction of the Palmer drought severity index (PDSI) for North Carolina (Stahle et al. 1988). This reconstruction contributed to the discovery of a multi-decadal moisture cycle over the past 1,600 years for North Carolina (Stahle et al. 1988, Stahle and Cleaveland 1992, Stahle et al. 1998). Subsequent field and laboratory research has produced a 1,645-year tree-ring chronology that

dates from AD 365 to 2010 (Figure 5; Wolff 2012), one of the longest tree-ring chronologies in the world.

The discovery of dozens of millennium-age baldcypress at Black River spurred continued interest in conservation of the area. The great longevity of the forested communities along the river has surprised many because some of the trees are extremely stunted. The acidic, nutrient-poor water and soils in which these ancient trees stand cause them to grow at an extraordinarily slow rate, so that they achieve impressive age without achieving great size (Stahle 1996). Furthermore, the stunted form of blackwater swamp baldcypress reduced its timber value and allowed many tracts to be spared from logging (Stahle 1996, Stahle et al. 2012). The Nature Conservancy now owns or manages conservation easements on more than 3,000 acres along the banks of the Black River and over 15,000 acres within the Black River watershed (Figure 6). Other tracts along the river are monitored or owned by Cape Fear River Watch and the North Carolina Coastal Land Trust. Although the Black River may be underutilized for outdoor recreation by the surrounding community, conservation managers lead interested parties on group boat trips down the Black River several times a year (Angie Carl, Kemp Burdette and Charles Robbins, personal communication, March 23-26, 2015).

Despite productive conservation efforts throughout the Black and adjacent Cape Fear and Northeast Cape Fear Rivers, bottomland hardwood forests and their surrounding wetland waters have remained vulnerable in the decades since their longevity was discovered. Some of these tracts are for sale and are being examined for potential purchase by various conservation organizations. Riverfront real-estate development, industrial limestone quarries, clear-cutting operations that manufacture garden mulch from baldcypress, and nutrient run-off from concentrated animal feeding operations (CAFOs) threaten to erode the ecological and

hydrological integrity of the Black River wetland system (Burdette et al. 2014). The Cape Fear and Black River watershed contains the highest concentration of CAFOs in the world, while regulations governing the disposal of animal waste are "almost non-existent" (Burdette et al. 2014). Nitrogen and phosphorous levels have increased at some places along Black River, whose water has historically been characterized by its outstanding quality and extremely low nutrient levels (Kemp Burdette, personal communication, March 26, 2015). In the face of many threats, several forested tracts remain unprotected along the Black River and may contain important communities of ancient baldcypress. Information about the presence of ancient baldcypress forests on these unprotected properties could help direct future land conservation efforts.

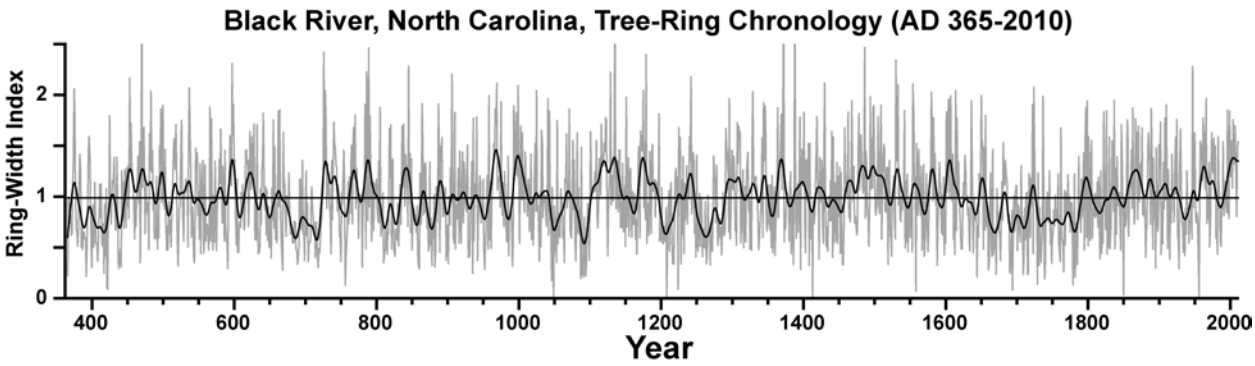

Figure 5: The standardized time-series of mean ring width values from trees at Black River, North Carolina, is the longest available baldcypress tree-ring chronology, dating from AD 365 to 2010 (David Stahle, personal communication, April 7, 2015). The inter-annual and decadal variability in ring width at Black River is strongly correlated with spring precipitation and soil moisture. Note the trend of improving tree growth and inferred higher moisture levels from the 17th to 21st century.

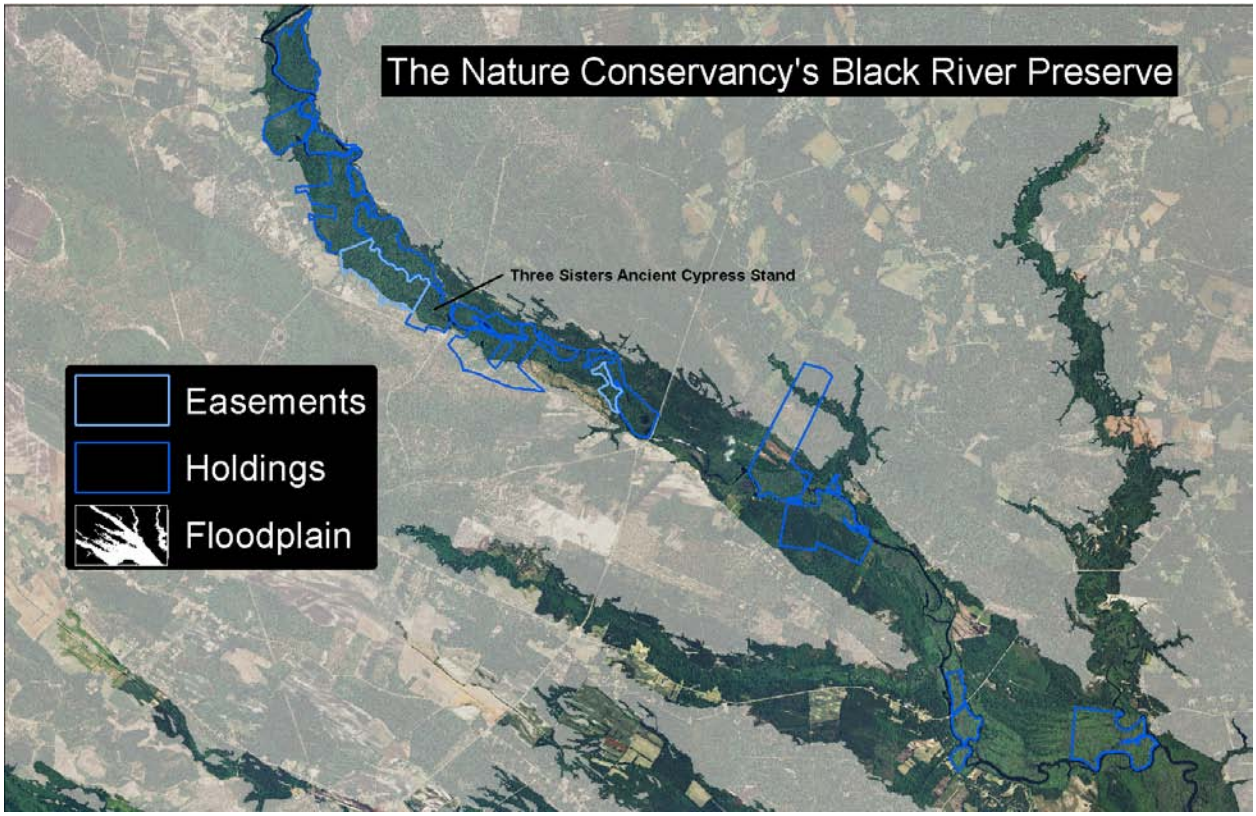

Figure 6: The Nature Conservancy owns or manages conservation easements on 3,016 acres of floodplain and waterfront habitat along Black River, North Carolina (indicated as "holdings and "easements," respectively, in the legend). This collection of wetland properties is named the "Black River Preserve" and includes the Three Sisters natural area, which appears to contain the most extensive and oldest stand of ancient baldcypress yet found.

Chapter 4: Data and Methods

Aerial photo interpretation was used to identify areas of old-growth baldcypress along Black River that are not currently under conservation management. High-resolution, multispectral aerial imagery collected by the National Agricultural Imaging Program was obtained for the study region and examined to locate tracts of forest with open canopies and flooded understories that are immediately adjacent to the lowest-lying channels within the river corridor. NAIP imagery contains blue, green, red and near-infrared bands at 1-meter spatial resolution, and is flown in 3-year intervals across the entire United States during growing season months (Figure 7).

Target old-growth areas were based on the image characteristics of old-growth tracts previously identified by the UAF TRL (Figure 8). These old-growth baldcypress stands along Black River, North Carolina, exhibit distinct color, texture, site, situation and association characteristics that can be used to discriminate them from surrounding land cover classes present in the high-resolution aerial imagery. Baldcypress stands appear more brownish-gray than darker-green stands of upland pine or adjacent bright green stands of pure hardwoods on the seasonal NAIP image used. Old-growth baldcypress canopies exhibit a “cobbled” or “granular” texture with irregularly distributed shadows, tree crowns and canopy gaps, through which dark patches of flooded understory are visible (Figure 8). This granular texture is especially apparent in inundated stands located on the margins of calm backwater sloughs away from the main channel. Though old-growth baldcypress and bottomland-hardwood forests extend beyond these open-water slough areas into more closed-canopy stands on higher ground, areas with distinctly cobbled canopy textures visible on side channels of Black River were the most likely locations of old-growth forest from which to begin field verification of stand ages (Figure 9).

Image interpretation focused on threatened habitat by limiting target old-growth areas to those not within public land ownership or conservation easement boundaries, which were obtained from North Carolina's OneMap geospatial data clearinghouse (Chapter 3, Figure 6). A digital elevation model for the study area was obtained from the National Elevation Dataset, which is compiled by the U.S. Geological Survey (USGS) using a combination of orthoimagery- and LiDAR-derived (Light Detection and Ranging) elevation data. Image interpretation was limited to low-lying positions within the Black River corridor by extracting only the portions of high-resolution NAIP imagery that fell below five meters in elevation (Figure 10).

Areas identified with aerial photo interpretation as previously unknown old-growth forest not under conservation management were verified using field data collection and documentation (Table 2). The field team included Dr. David Stahle, Ms. Jordan Burns and Mr. Graham Hawks. David Stahle has more than three decades of experience with the field identification of old-growth trees for dendrochronology and conservation. During five years of work at the UAF TRL, Jordan Burns has participated in the field analysis of old-growth forests in Colorado, Florida, Oklahoma and Arkansas. Graham Hawks has training in forest ecology, biogeography and dendrochronology. He also has three decades of experience with land acquisition, conservation and management.

The old age of target forest stands was confirmed during field exploration using expert visual assessment and photographic documentation of growth characteristics common to ancient baldcypress trees: laterally twisted trunks, hollow voids, crown die-back, spike-tops, under-fit crowns, and the growth of resurrection fern (P*leopeltis polyspodioides*) and other species on the ancient branches. The old age of selected trees at each target area was then verified using cores extracted using an increment borer. The selected trees were not randomly sampled and the age

data are provided only as an example of the longevity of trees in these stands. Cores were mounted and polished and tree-ring analysis (dendrochronology) was used to determine tree age (ring counts are also provided for cores that were not dated; Tables 2 and 3).

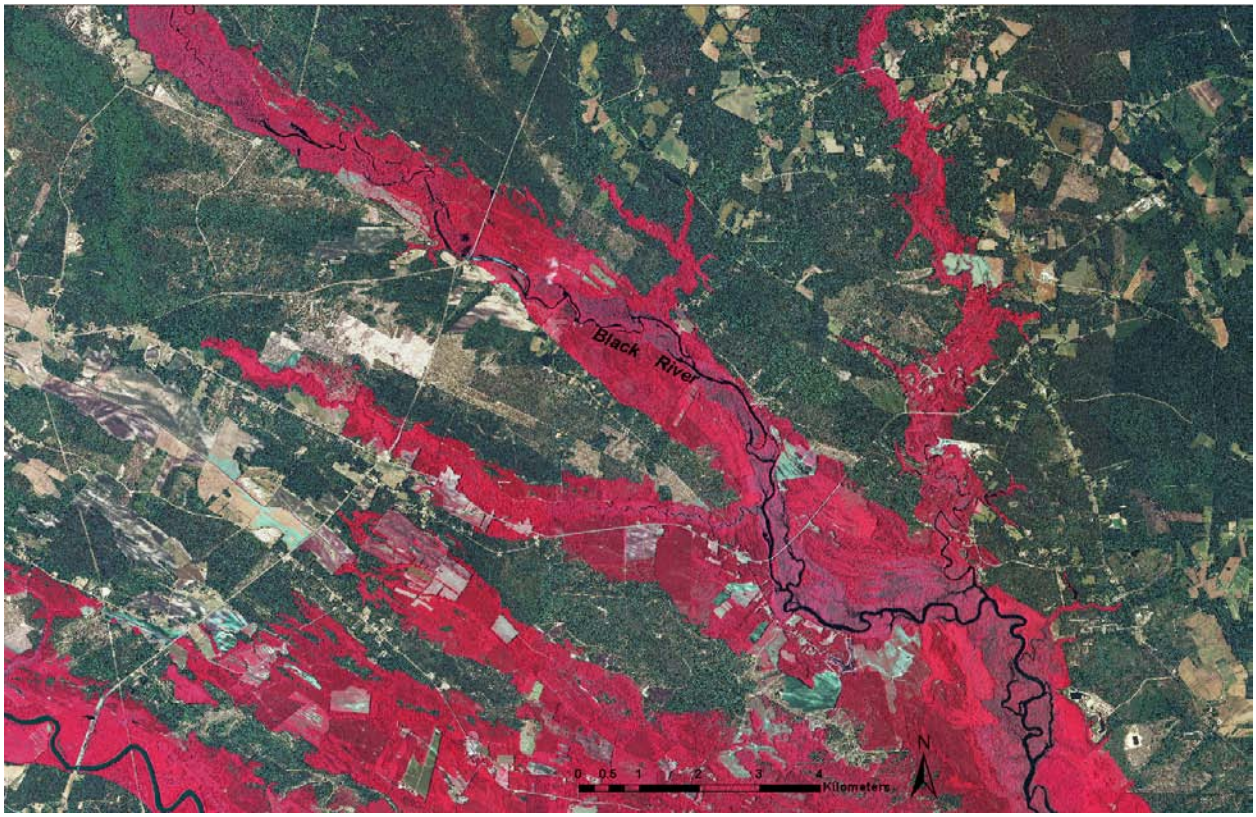

Figure 7: The National Agricultural Imaging Program (NAIP) collects 1-meter, 4-band orthoimagery over the entire United States during growing season months. The river corridor (below five meters elevation) is shown in false color above. The near-infrared band is useful for discriminating vegetation in high-resolution imagery.

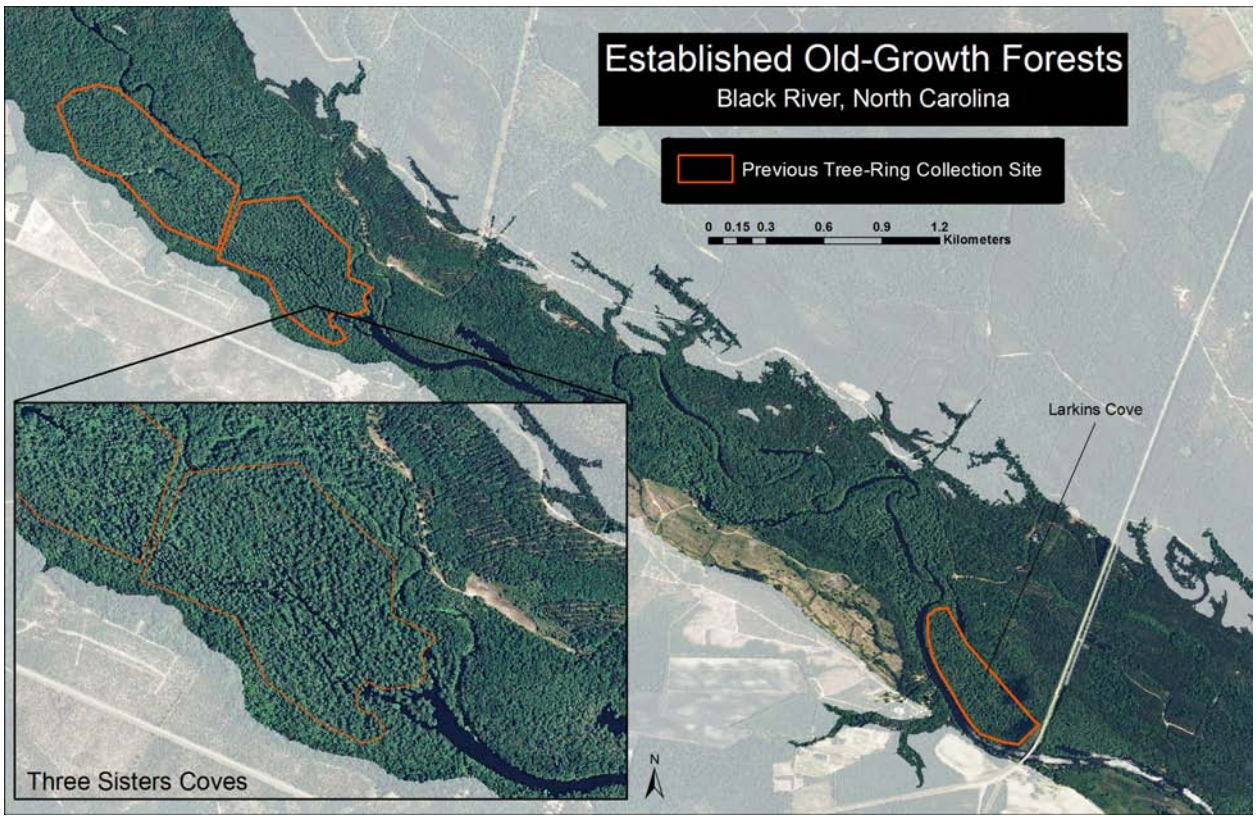

Figure 8: Previously identified old-growth baldcypress tracts on Black River include forests at the Three Sisters coves and Larkins Cove. The Three Sisters stand contains the oldest known baldcypress tree (BLK69), and the oldest-known living tree in eastern North America. In NAIP orthoimagery, old-growth stands exhibit a cobbled forest pattern that may be caused by flooded understories and widely spaced canopy crowns.

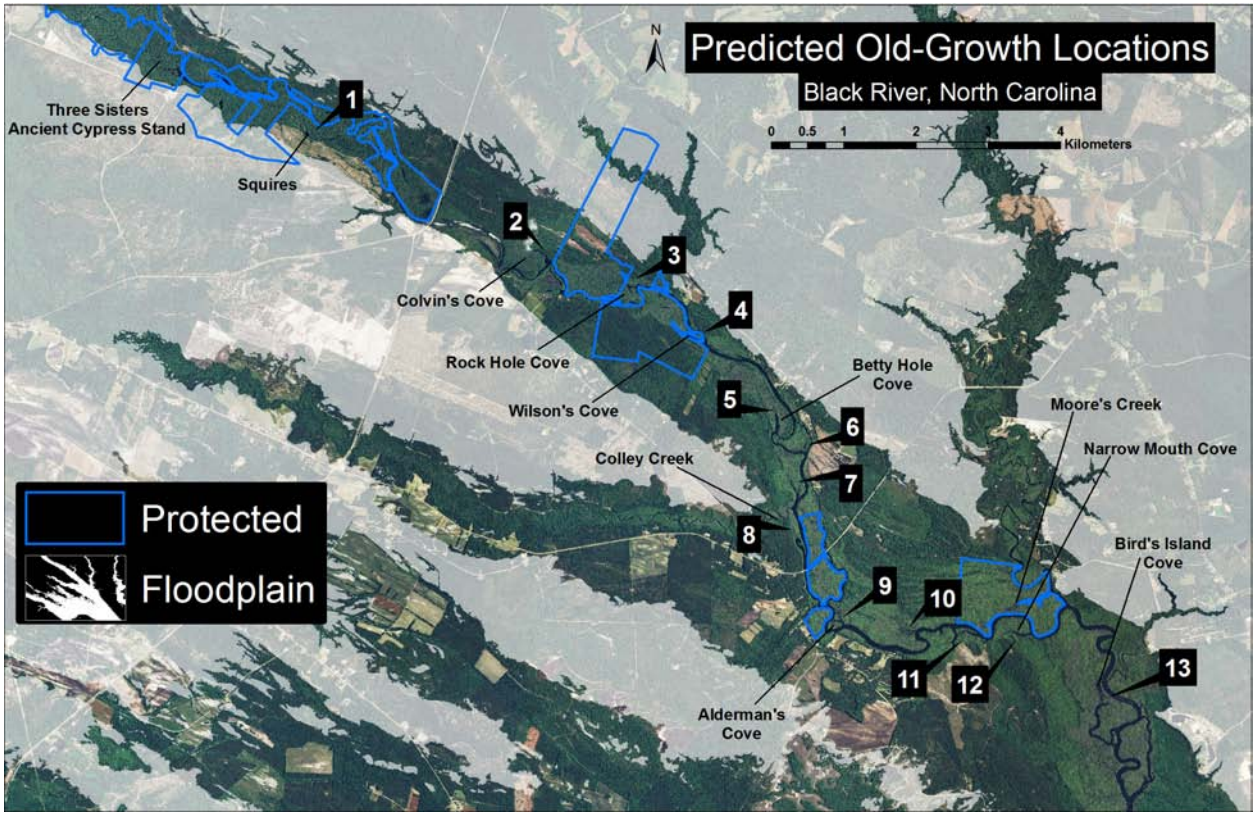

Figure 9: Candidate locations for old-growth baldcypress stands were identified based on their resemblance in aerial imagery to previously identified old-growth stands at Three Sisters Cove and Larkins Cove (site locations 1 – 13 above).

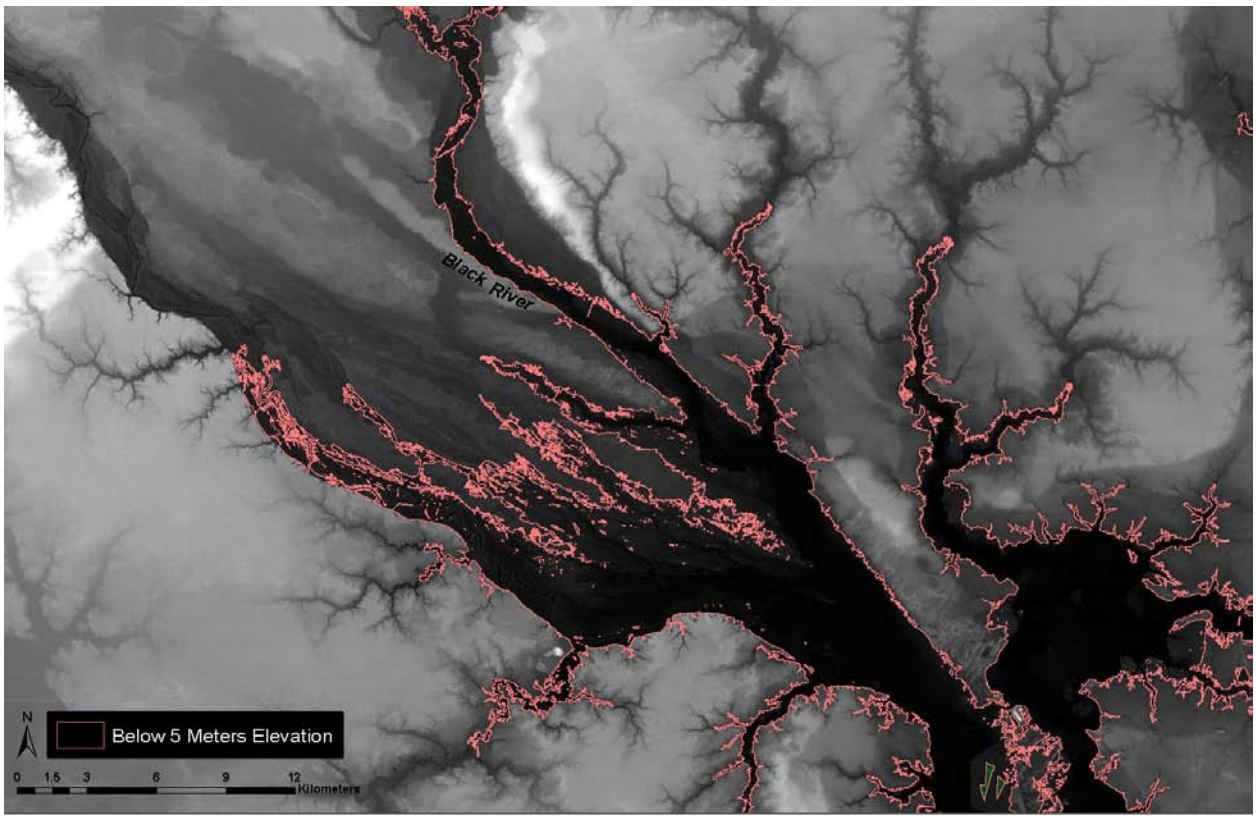

Figure 10: Digital elevation data compiled by the USGS at approximately 3-meter resolution was obtained for the study area and used to isolate the low-lying floodplain habitat of baldcypress on Black River and surrounding streams. Ancient baldcypress stands on Black River are found almost exclusively below five meters in elevation (outlined in red above).

Chapter 5: Results

A total of 15 noncontiguous parcels of previously unidentified ancient forest, accounting for approximately 1,035 acres were found along Black River (Table 1; Figure 11). Five tracts of selectively logged areas containing significant numbers of ancient "cull" trees accounted for 262 acres of this total. The remaining 10 tracts of newly identified old-growth forest constitute 773 acres of what appeared to be uncut, ancient baldcypress and bottomland hardwood forest. Of the 10 newly identified uncut old-growth tracts, 8 tracts representing 674 acres are not currently under conservation management and 6 of these tracts share a border with areas currently owned or managed by The Nature Conservancy. However, the full extent of the newly identified old-growth forests could not be evaluated in the field because the water level was too high to permit on-the-ground examination of closed canopy stands away from open water channels. Therefore, the total area of unprotected old-growth baldcypress found during our March 2015 field trip should be considered as a minimum estimate. The age of targeted old-growth tracts was documented using photographs, which are shown for each newly identified area along with corresponding maps in Figures 12 – 19, and tree-ring data from increment core samples of selected old trees, which are summarized in Table 2.

Aerial photo interpretation of forested land along Black River revealed that the distinct structural and site characteristics of old-growth baldcypress canopies on blackwater streams are visible in high-resolution imagery and may be useful for the identification of ancient forests for conservation purposes when examined carefully by a trained analyst. The tall, crooked and sparsely distributed canopies of some ancient cypress stands were expressed in NAIP imagery as granular patches of rough, brownish-green forest underlain by intermittent spots of dark charcoal-colored water that floods the understory of these backchannel forests (Figures 12 – 19).

These distinct patches coalesce around the margins of sluggish sloughs that depart from the main river channel and taper out of sight beneath increasingly dense bottomland forests. In fact, the best areas of intact ancient baldcypress are often found on quiet-water sloughs away from the main channel of the Black River. These deeply flooded stands tend to be dominated by baldcypress and pop ash (*Fraxinus caroliniana*). They seem to grade into mixed baldcypress and bottomland hardwoods in shallower water and eventually into pure bottomland hardwoods on higher natural levees on the floodplain. The degree of past logging disturbance also seems to follow this subtle topographic and hydrological gradient, with the lowest-lying baldcypress stands often uncut and the pure hardwoods on higher levees heavily cut over. Where exactly the transition between previously cutover and uncut forests is found along the Black River will require additional field and laboratory research. Nevertheless, our identification of old-growth parcels (Figure 11) has been conservative and largely confined to the lowest baldcypress stands with old trees that could be seen from the boat in open water during leaf-off conditions of March 2015.

The model for aerial interpretation of old-growth forests on Black River described above was also employed at Island Creek, a small tributary of the nearby Northeast Cape Fear River, which is also a blackwater stream. Forest stands along Island Creek fell within our target elevation area of below five meters above sea level and some canopies exhibited a granular pattern in the NAIP imagery similar to that associated with the flooded and sparse canopies of old-growth tracts on Black River (Figure 21). Twelve baldcypress trees were cored at Island Creek, one of which is over 1,020 years old and three of which are over 500 years in age (Table 3). Though bottomland hardwood stands along Island Creek appear to have been selectively

logged more extensively than even the selectively logged stands at Black River, hundreds of additional old baldcypresses are present along Island Creek, covering some 72 hectares.

Name	Minimum Size (hectares)	Quality	Status
Squires Tract	32	Uncut	Unprotected
Colvin's Cove	42	Uncut	Unprotected
Rock Hole Cove	9	Uncut	Unprotected
Wilson's Cove	29	Uncut	Protected
	5	Selectively Logged	Unprotected
Betty Hole cove	78	Uncut	Unprotected
Collie Creek	14	Selectively Logged	Unprotected
Alderman's Cove	23	Uncut	Unprotected
	15	Selectively Logged	Unprotected
Narrow Mouth Cove	4	Uncut	Unprotected
Moore's Creek	11	Uncut	Protected
Bird's Island Cove	85	Uncut	Unprotected
Island Creek	72	Selectively Logged	Unprotected

Table 1: Size and status of previously undocumented old-growth forest tracts identified in and near Black River, North Carolina (For this table, two small tracts at Collie Creek are combined, as well as two uncut and two selectively logged tracts at Alderman's Cove).

Sample ID	Location	DBH (cm)	Radius of xylem (cm)	Ring count	Dating	Status
BLK01	Squires			217	1768-1984	Unprotected
BLK02	Squires			445	1540_{np} -1984	Unprotected
BLK03	Squires			492	1493-1984	Unprotected
BLK04	Squires			251	1734-1984	Unprotected
BLK05	Squires			250	1735-1984	Unprotected
BLK09	Squires			126	1859-1984	Unprotected
BLK10	Squires			987	998-1984	Unprotected
BR501A	Squires	51				Unprotected
BR502A	Squires	99	45.2	1,026		Unprotected
BR503A	Squires	89		714		Unprotected
BR503B	Squires		21.0			Unprotected
BR504A	Squires		28.4	358	1657_{fp} -2014	Unprotected
BR505A	Colvin's Cove	43	17.4	628		Unprotected
BR506A	Colvin's Cove	46	7.5	296		Unprotected
BR507A	Colvin's Cove	56	28.5	796		Unprotected
BR508A	Colvin's Cove	53	25.5	1,067		Unprotected
BR509A (Loblolly)	Colvin's Cove	41	16.4	93		Unprotected
BR510A (Tupelo)	Colvin's Cove		13.2	336		Unprotected
BR511A	Colvin's Cove	71	33.5	1,297		Unprotected

BR512A	Colvin's Cove	64	24.7	921	Unprotected
BR513A	Colvin's Cove	43	21.1	973	Unprotected
BR514A	Rock Hole Cove	66		1,099	Unprotected
BR514B	Rock Hole Cove		34.4		Unprotected
BR515A	Rock Hole Cove	56	11.7	189	Unprotected
BR516A	Rock Hole Cove	58			Unprotected
BR516B	Rock Hole Cove		17.3	785	Unprotected
BR517A	Wilson's Cove	51	9.1	300	Protected
BR518A	Wilson's Cove	31	15.1	854	Protected
BR519A	Betty Hole Cove	71			Unprotected
BR519B	Betty Hole Cove		36.4	1,394	Unprotected
BR520A	Bird's Island Cove	76	37.2	1,426	Unprotected
BR521A	Bird's Island Cove	86	17.6	389	Unprotected
BR521B	Bird's Island Cove				Unprotected
BR22A	Alderman's Cove	71	12.3	477	Unprotected
BR22B	Alderman's Cove				Unprotected

Table 2: Analytical results for increment cores collected from selected old trees at Black River, North Carolina, March 2015, are listed along with estimated diameter of tree at breast height (DBH), core length (many trees were hollow so dated ages or ring counts seriously underestimate true age). The 'status' column refers to ownership by a state or conservation organization (protected) or other private ownership (unprotected).

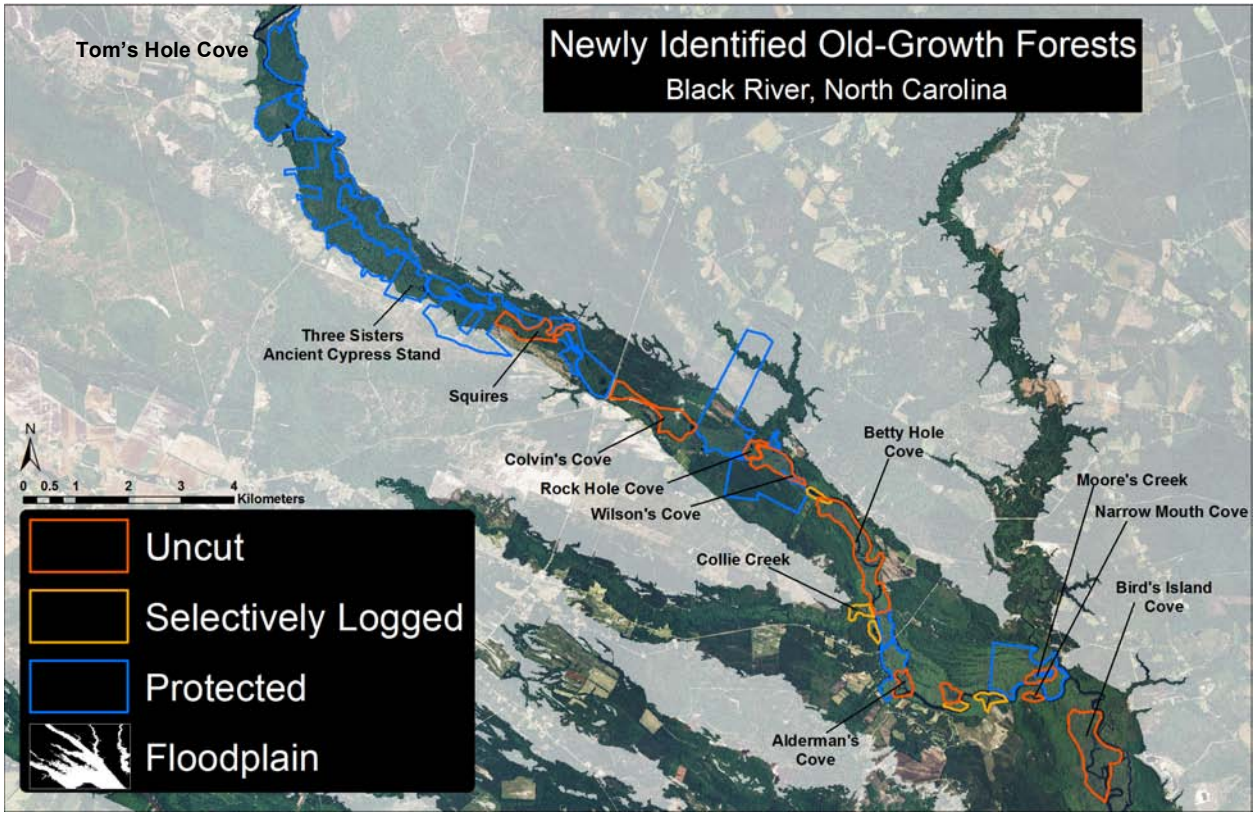

Figure 11: Approximately 419 hectares (1,035 acres) of previously unidentified old-growth baldcypress stands in 15 separate parcels were mapped along Black River. Ten of these parcels (313 hectares; outlined in orange above) appeared to be uncut old-growth baldcypress stands with dozens to hundreds of ancient trees depending on the size of the tract. Five of the mapped parcels (106 hectares; outlined in yellow above) contained what appeared to be selectively logged stands with ancient "cull" baldcypress trees. Newly identified old-growth stands at Wilson's Cove and Moore's Creek (40 hectares total) are currently under conservation management by The Nature Conservancy. The remaining uncut and selectively logged ancient baldcypress parcels account for nearly 1,000 acres and are privately held and may be vulnerable to destruction. Their incorporation into existing conservation efforts along Black River could protect 21 continuous river miles of ancient forest.

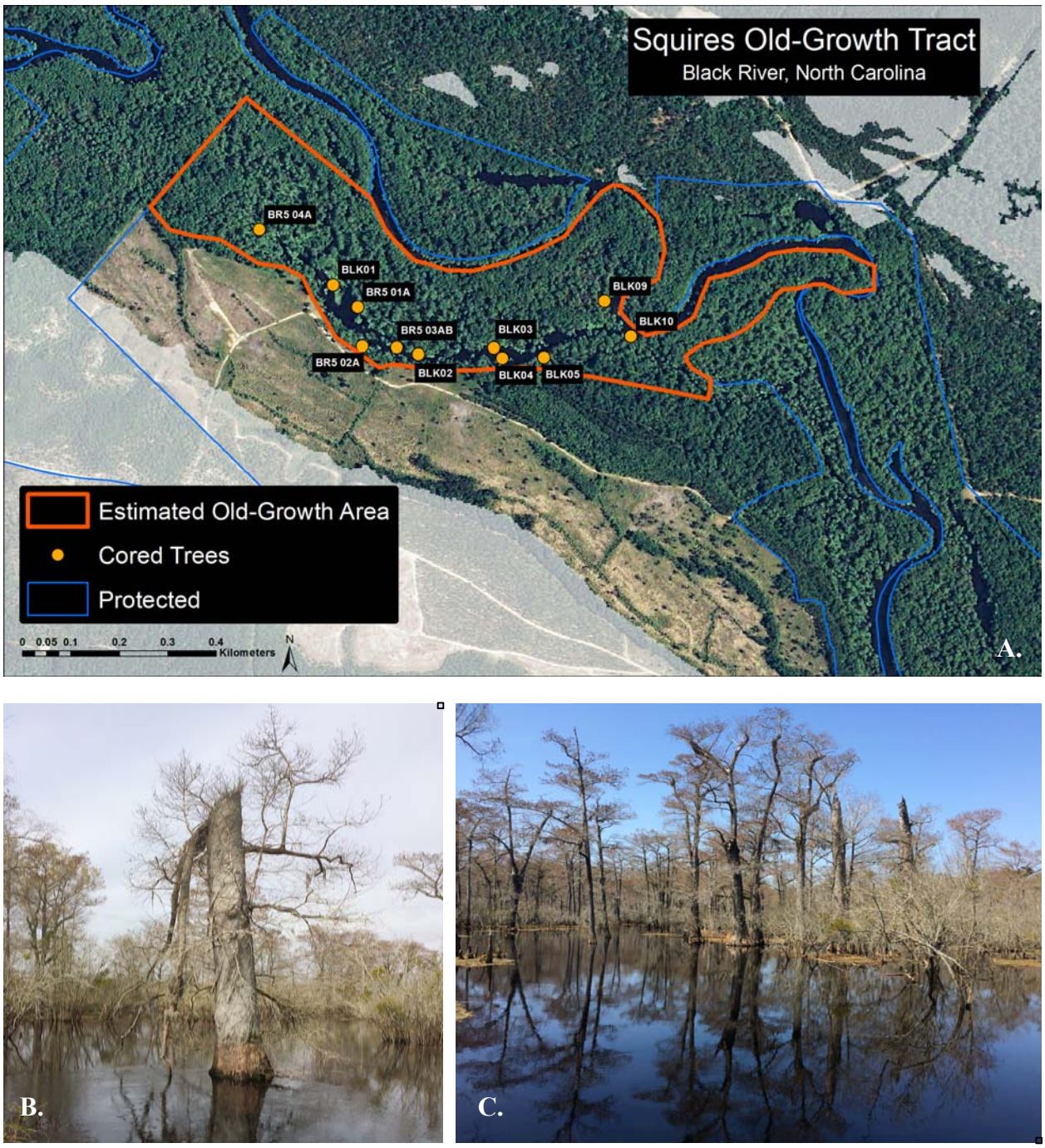

Figure 12: Unprotected old-growth baldcypress stands are illustrated at the Squires property (A, B). Note the extreme lateral twist, broken branch and small, under-fit canopy branches of the tree from which sample BR5 03A and B were taken (B), which has a DBH of 89 cm, is at least 714 years old based on a 21 cm increment core, and is likely well over 1,000 years old.

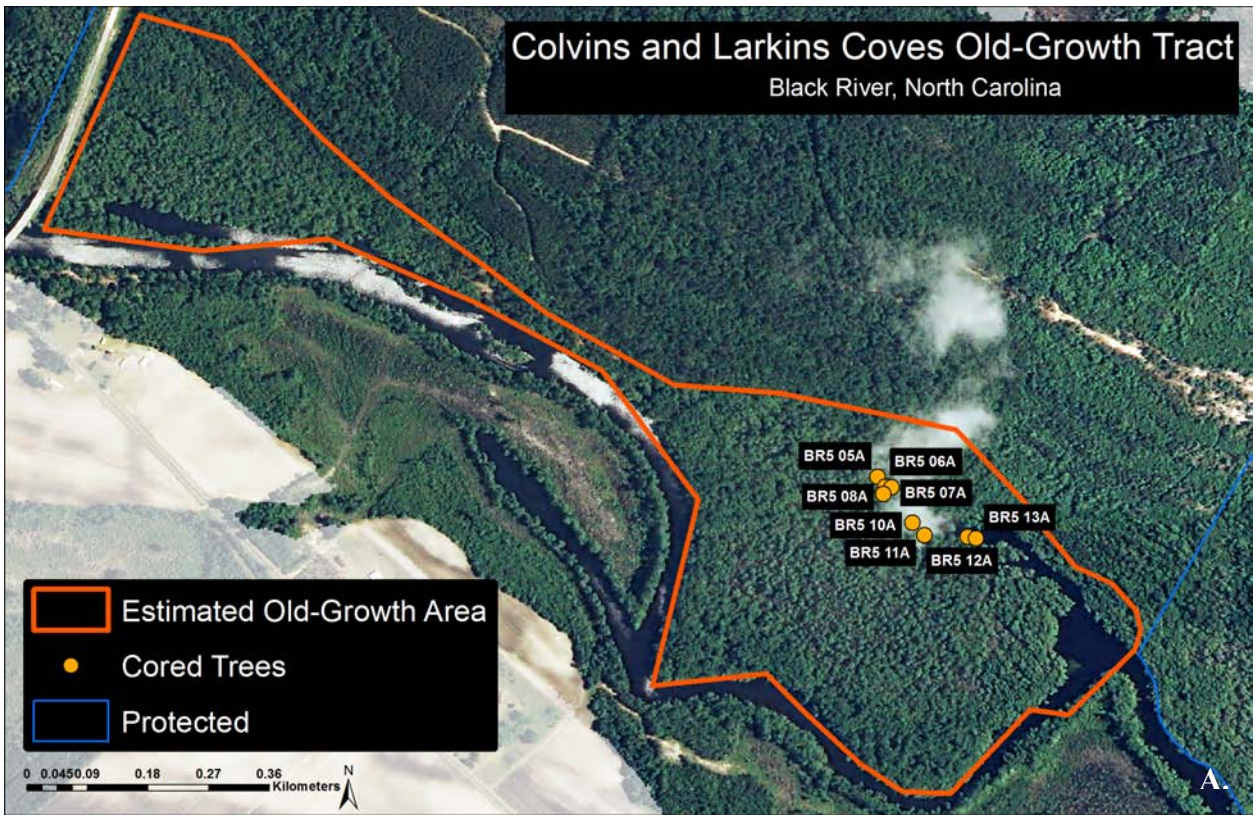

Figure 13: This map outlines the unprotected old-growth stands at Colvin's and Larkins Cove, a parcel bordering protected Nature Conservancy tracts on two sides (A). Note the crooked, asymmetrical, under-fit baldcypress canopies in the foreground (B).

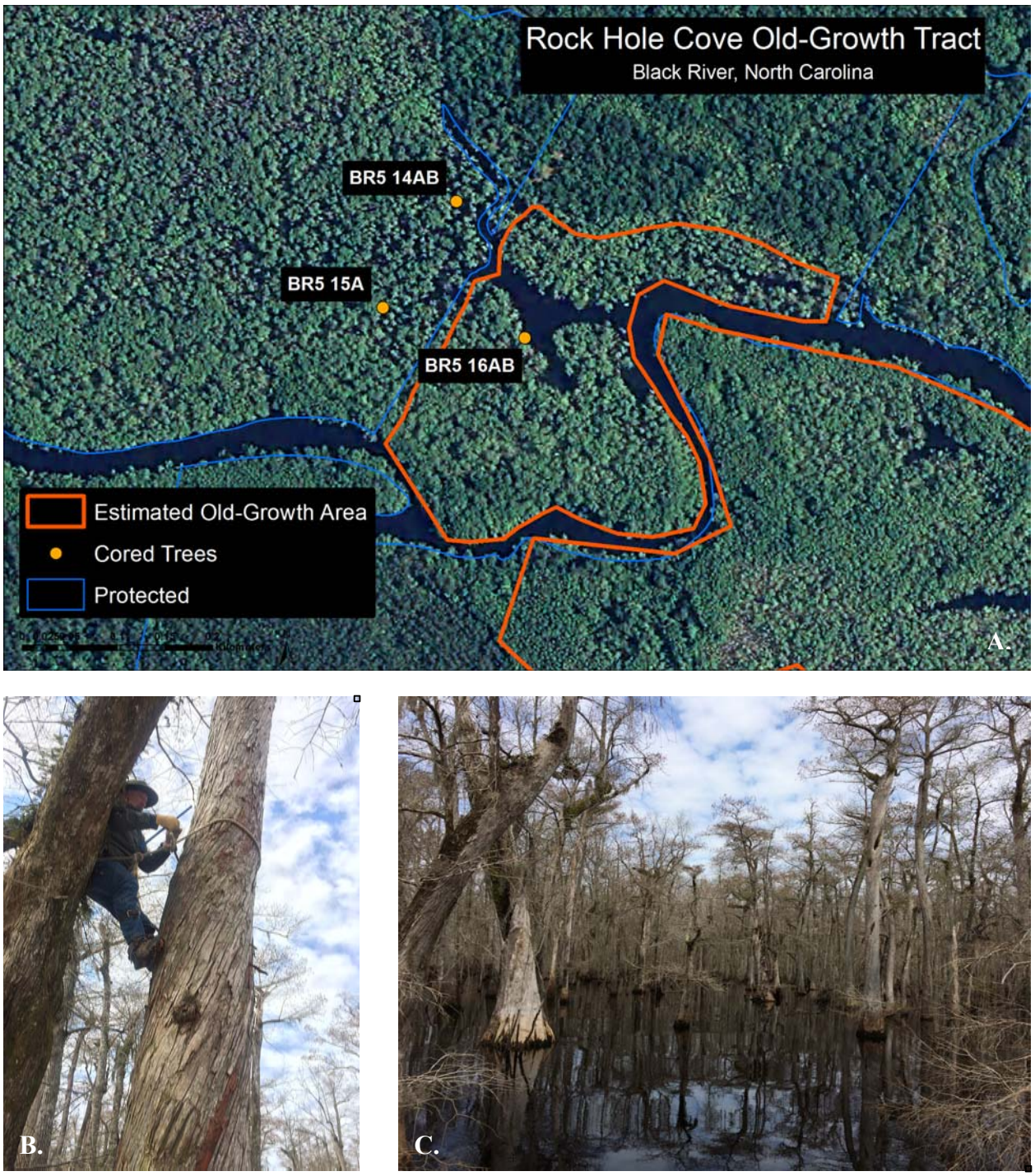

Figure 14: A small tract of old-growth baldcypress on unprotected property at Rock Hole Cove is bordered on both sides by The Nature Conservancy's holdings (A). Note the lateral twist on BR5 14 (B), which has a DBH of 66 cm and at least 1,099 annual rings. Rock Hole Cove contains tranquil waters and hundreds of stunted, old-growth baldcypress trees (C).

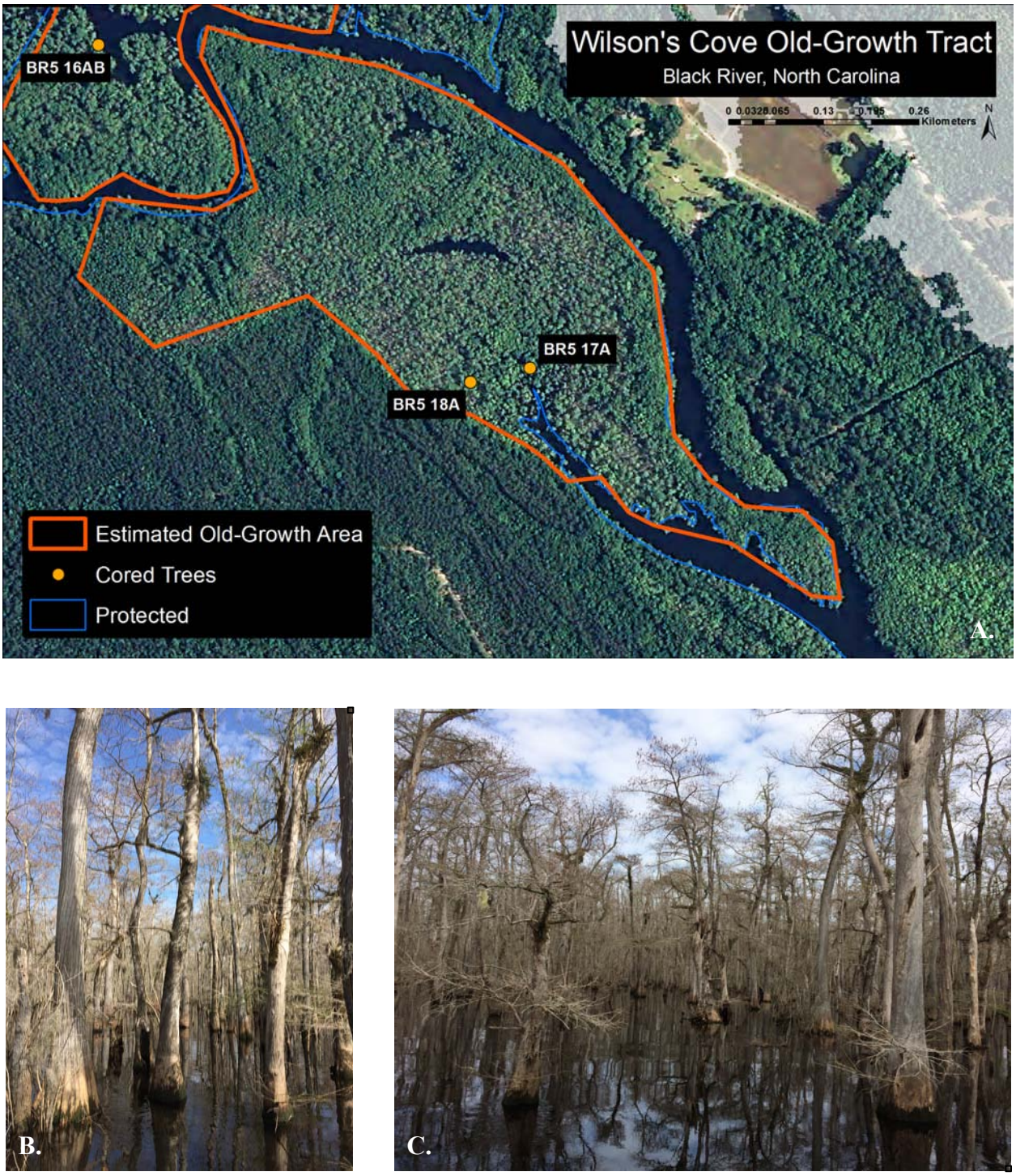

Figure 15: Newly identified old-growth baldcypress stands at Wilson's Cove, a tract managed by The Nature Conservancy (A). The tree (BR5 18) at center (B) has a DBH of only 31 cm, but it is at least 854 years old. Note the extreme lateral twist of this stem and the heavy growth of resurrection fern in the canopy, both strong indicators of longevity. Note the hollow voids in the far-right tree and the crooked, under-fit canopies (C).

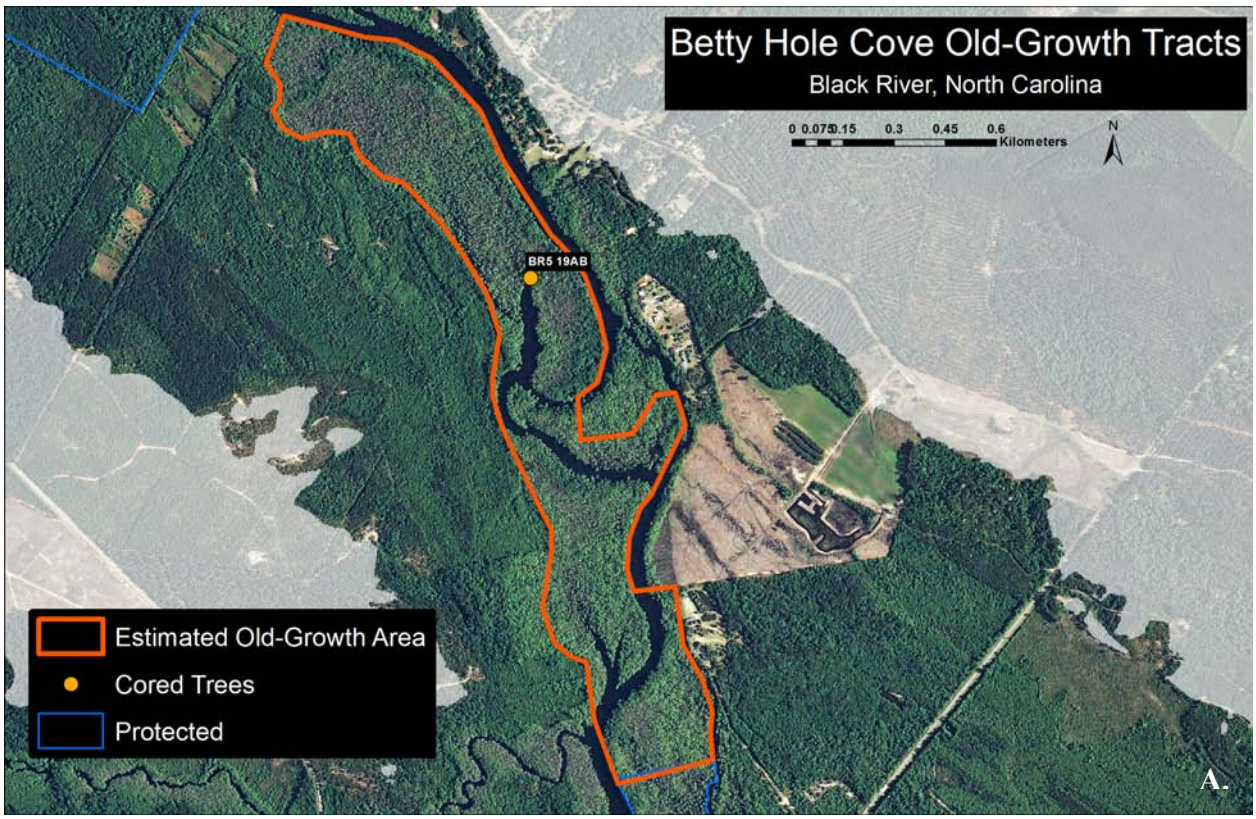

Figure 16: Extensive and beautiful stands of old-growth forest at Betty Hole Cove and nearby parcels contain hundreds of centuries-old baldcypress trees (A, B). Note impressive trunk size, flattop crowns and crooked limbs of ancient baldcypress (B).

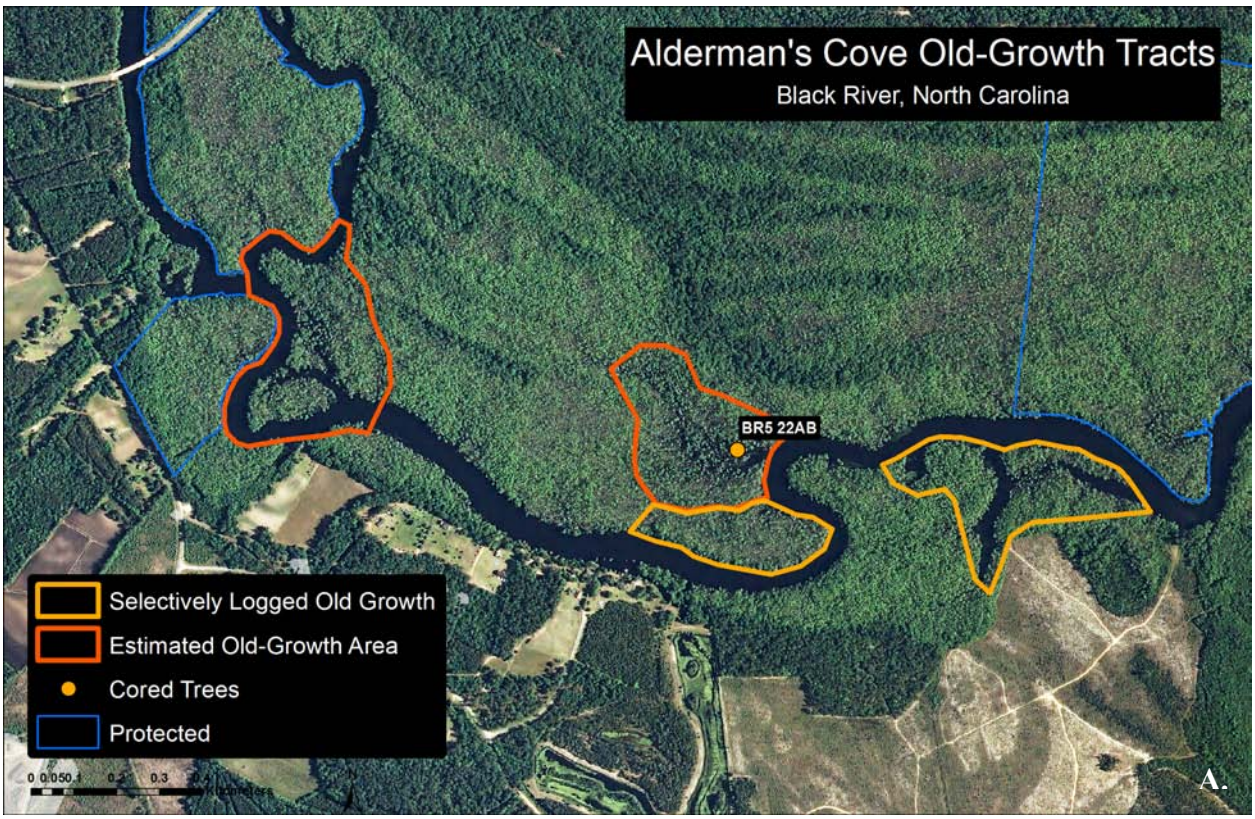

Figure 17: Unprotected old-growth baldcypress tracts are mapped in and around Alderman's Cove (A). An ancient, standing dead baldcypress tree is located in the middle of the flooded channel with thick forests of ancient baldcypress also in view (B). Dr. David Stahle samples a centuries-old, solid baldcypress tree (BR5 22) that has a DBH of 71 cm and is at least 477 years old.

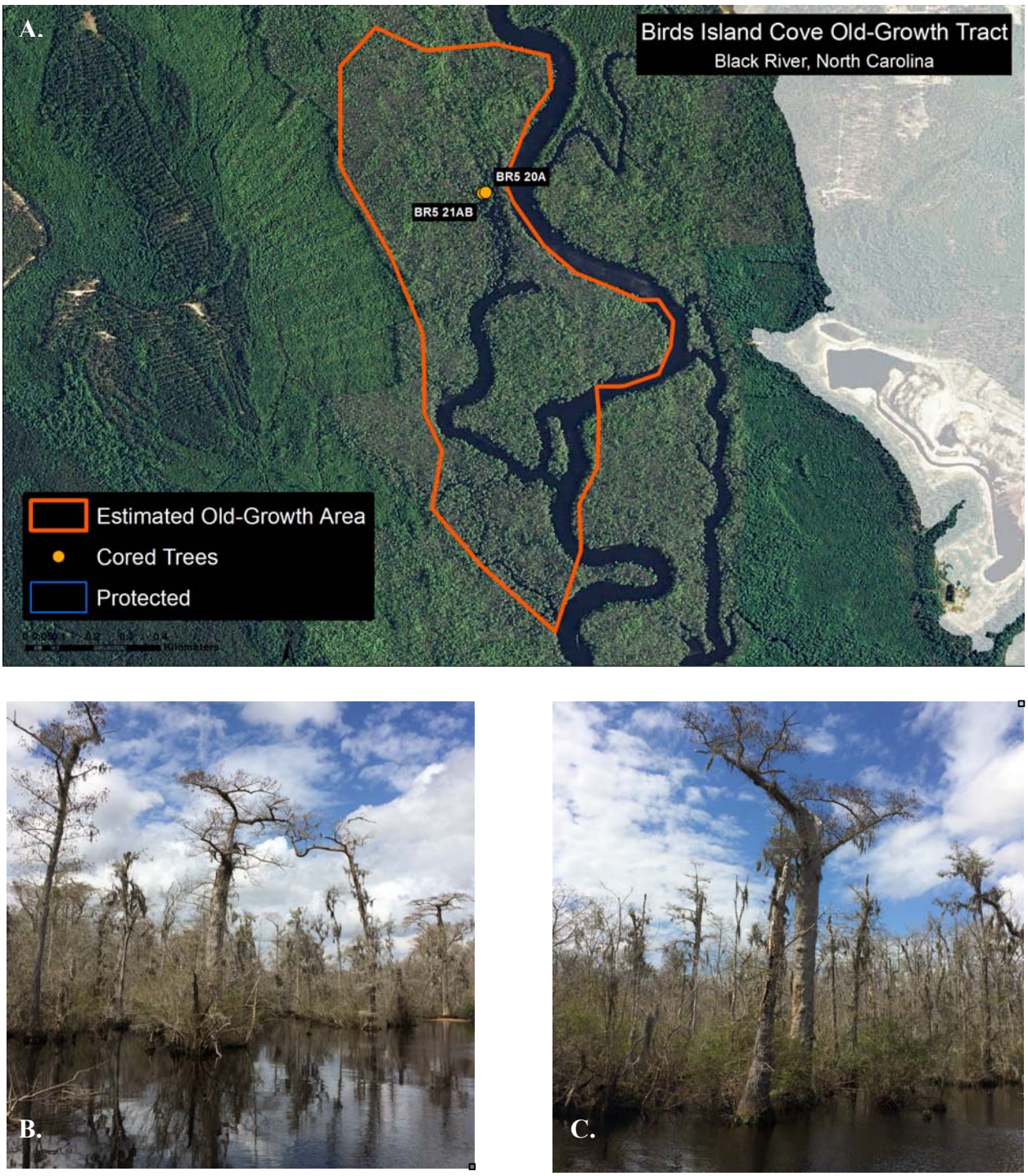

Figure 18: Ancient baldcypress stands at Bird's Island Cove (A) exhibit dense understories of pop ash and holly and contain some of the most impressively large baldcypress identified on unprotected private property during this project (B, C). Note the structural characteristics quintessential to ancient baldcypress (B, C). The fourth oldest known tree in eastern North America was sampled (BR5 20) with a DBH of 76 cm and at least 1,426 annual rings.

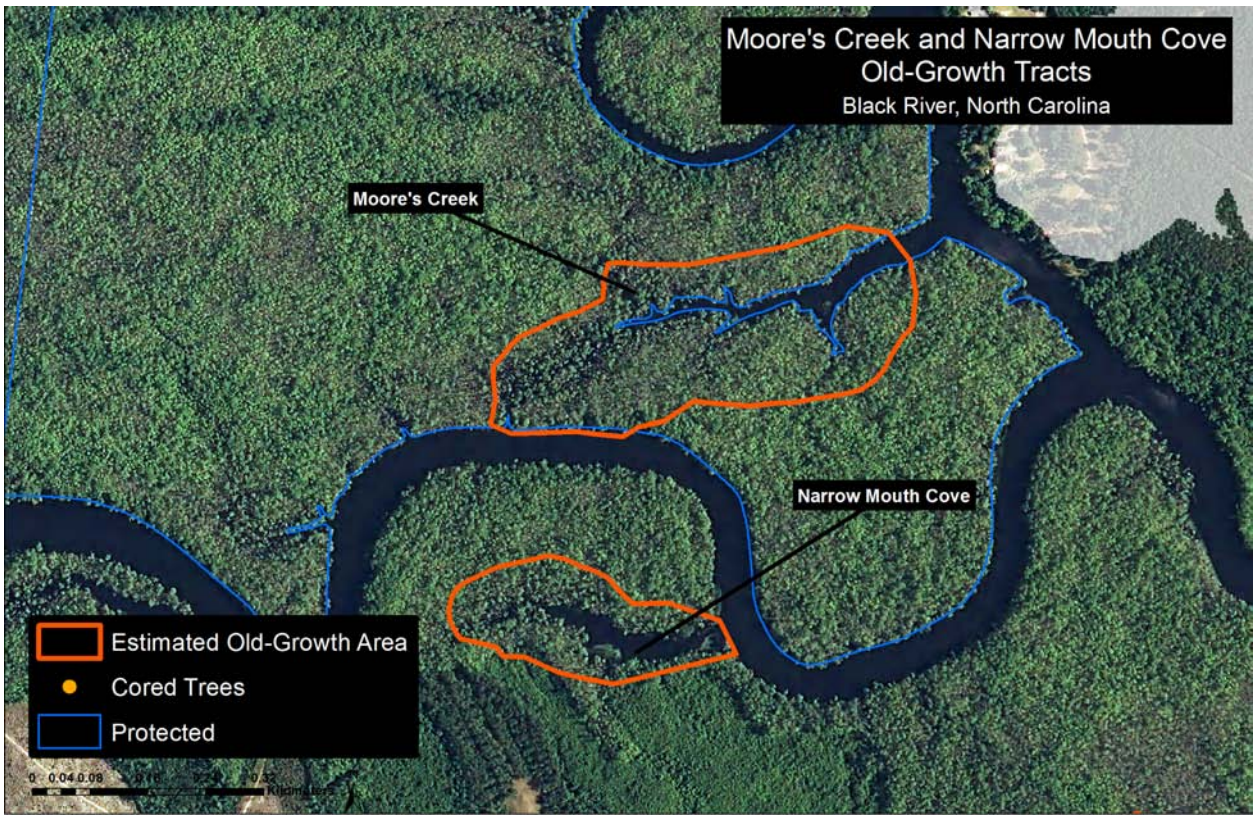

Figure 19: Newly identified old-growth baldcypress stands flank the lower portion of Moore's Creek and property protected by The Nature Conservancy. A smaller tract of uncut old-growth baldcypress along nearby Narrow Mouth Cove is on private property not believed to be in conservation management.

Figure 20: An age class histogram for 103 sampled baldcypress trees from Black River is illustrated and includes data collected during this project and previous fieldwork. Though biological age class distributions typically approximate a negative exponential curve, the distribution of ages for baldcypress at Black River is skewed because samples were selected for longevity. Note the cluster of baldcypress samples around the 1,000-year age class, an age reached by perhaps only a dozen tree species in the world. At Black River, millennium-age trees are abundant, and many samples around the 300-year age class were taken from hollow trees and are likely much older. Data collected during this project include the fourth and fifth oldest living trees sampled in eastern North America, whose core samples contain 1,426 and 1,394 annual rings, respectively.

Sample ID	DBH (cm)	Radius of xylem (cm)	Ring count	Dating
ISL01A	81	29.0	931	
ISL01B				
ISL02A	38	22.5	789	
ISL02B		20.0		
ISL03A	97	38.3	398	
ISL03B				
ISL04A (loblolly)	48	15.5		
ISL05A (subfossil)		23.7	411	
ISL06A	66	30.5	979	1015-2014
ISL06B				
ISL07A	76	16.5		
ISL07B		19.0	806	
ISL08A	71	15.3	361	1654-2014
ISL08B				
ISL09A	46	21.5		
ISL09B		23.5	233	
ISL10A	66	5.5		
ISL10B		6.0	185	
ISL11A	102	15.8	603	
ISL11B				
ISL12A	56	27.5	210	1804-2014
ISL12B				

Sample ID	DBH (cm)	Radius of xylem (cm)	Ring count	Dating
ISL13A	41			
ISL13B		17.2	290	1724-2014
ISL14A	66	30.5		
ISL14B		31.0	813	

Table 3: Analytical results for increment cores collected from trees at Island Creek, North Carolina, March 2015, are listed along with diameter of tree at breast height (DBH) and core length. Many trees were hollow, so dated age or ring counts seriously underestimate true age. Note that the increment cores taken from ISL 01, 07, 08, 10 and 11 contain hundreds of rings but represent only a small fraction of each tree's true radius.

Figure 21: Old-growth baldcypress-bottomland hardwood forests (A) were identified at Island Creek, a blackwater tributary of the Northeast Cape Fear River (B), on March 25, 2015. Some of this tract appears to have been selectively logged, but pockets of ancient trees survive. Core samples were extracted from 12 living baldcypress trees, one loblolly pine and one subfossil baldcypress log. Two sampled trees are in the 1,000-year age class and hundreds of additional centuries-old trees are still present along Island Creek.

Chapter 6: Summary and Conclusions

The 15 old-growth baldcypress forests identified during this research represent over 400 hectares of high-priority habitat for conservation on Black River. These newly identified areas contain hundreds of trees over 500 years old and many trees exceeding 1,000 years in age. This project also indicates that ancient baldcypress forests extend almost continuously from the upstream end of Tom's Hole Cove to the southern end of Bird's Island Cove, approximately 21 river miles along the mid- to lower-Black River (Figure 11). The prevalence of old-growth baldcypress above Tom's Hole Cove and below Bird's Island Cove to the confluence of the Cape Fear River is not known, and these areas may contain additional ancient baldcypress stands. The numerous tracts of conserved wetland habitat surrounding the newly identified old-growth forests on Black River highlight the potential for future incorporation of these areas into conservation management. This incorporation could conserve at least 21 continuous miles of ancient baldcypress-bottomland hardwood habitat along the Black River and protect one of the most remarkable forested wetlands in the world.

The successful identification and mapping of critically endangered old-growth forests during this project demonstrates the efficacy of manual image interpretation for natural resource management. The distinct structural and site characteristics of ancient baldcypress stands made high-resolution photo interpretation useful for the identification of target conservation areas along Black River. However, a GIS-enabled predictive model could be combined with manual image interpretation and employed throughout the Southeast in order to identify additional candidate areas of remnant old-growth forest for conservation and research. An efficient predictive model might use a DEM to eliminate land cover classes above the lowest-lying floodplain corridor. Image segmentation techniques might then be applied to Landsat and

MODIS images in order to divide the remaining floodplain corridor into meaningful image objects at the stand-level (Baatz and Schäpe 2000, Drăguţ et al. 2010). Using image analysis software like eCognition, Landsat and MODIS image objects that are within the floodplain corridor and categorized as pine, young hardwood or developed land cover types could be eliminated. The remaining image objects would theoretically belong to the baldcypress-bottomland hardwood land cover class and the age of these remaining forest stands could be evaluated manually using high-resolution image interpretation or perhaps automatically using canopy structure metrics estimated from LiDAR data. Though automated classification techniques have been the focus of much recent land cover classification research, computer classification algorithms developed over the past several decades have yet to achieve the accuracy that is consistently achieved manually by image interpretation experts (Olson 2008).

Field exploration along Black River revealed that remote sensing-derived old-growth predictive models would need to discriminate between four main old-growth land-cover categories present along the forested river corridor: open-grown, inundated ancient baldcypress stands; denser, closed-canopy ancient baldcypress stands; mixed old-growth baldcypress and bottomland hardwood stands; and pure old-growth bottomland hardwood stands on higher ground and natural levees. All of these forested categories are valuable for the protection of ecological and hydrological integrity of Black River, but each appears slightly differently in high-resolution NAIP imagery. The future identification of additional old-growth areas within these categories could be further complicated by the sporadic presence of small bottomland pine stands throughout each forest type.

Despite being unprotected and not fully explored, the tranquil coves of twisted, ancient baldcypress along Black River are treasured by naturalists and conservation enthusiasts. The

fragmentary distribution of remnant stands discovered during this project underscores their importance as natural refugia in the deeply altered southeastern landscape. These old-growth areas provide habitat for many important bird species including the swallow-tailed kite, the wood stork and the prothonotary warbler (Dennis 1988). Additional areas of ancient bottomland baldcypress need to be identified and protected along lowland waterways in North Carolina in order to safeguard this diverse assemblage of rare, threatened and endangered faunal species, which are found in great abundance in old-growth wetland forests. The fact that ancient baldcypress were found on Island Creek proves that this can be done. The baldcypress-bottomland hardwood ecosystem is also vital for maintaining high water quality throughout the coastal lowlands of the Southeast and the protection of additional tracts of uncut bottomland forests along the Black River could contribute to the preservation of its status as an Outstanding Water Resource for the state of North Carolina.

Numerous threats to the hydrological integrity of Black River and surrounding streams have been documented in recent decades, including clear-cut logging for garden mulch and biomass harvesting for wood pellet stoves. Other serious threats include nutrient overload from animal feeding operations, mercury contamination and potential groundwater depletion by industrial mining ventures. Indeed, the majority of newly identified old-growth tracts mapped during this project are currently owned by timber or investment companies and lie immediately adjacent to areas of recently clear-cut upland and bottomland forest. Wetland habitat along Island Creek is imminently threatened by limestone mining, an issue that has created tension between supporters of the planned mining development and locals concerned for the integrity of water quality and biodiversity along the Northeast Cape Fear River. While many ancient baldcypress stands on Black River are currently vulnerable to destruction, their proximity to The Nature

Conservancy's numerous protected river corridor properties underscores the strong conservation ethos present at Black River. The identification of old-growth baldcypress forests within remnant wetland fragments in North Carolina and across the Southeast using high-resolution aerial imagery, other remote sensing data and field surveys could contribute to the targeted conservation of this unique and dwindling ecosystem.

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